A COINTEGRATION ANALYSIS OF HOUSE PRICE FORMATION IN THE HELSINKI METROPOLITAN AREA

Lauri Saarinen

University of Helsinki
Faculty of Social Sciences
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HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

Tiedekunta/Osasto – Fakultet/Sektion – Faculty	Laitos – Institution – Department
Faculty of Social Sciences	Department of Political and Economic Studies

Tekijä – Författare – Author
Lauri Saarinen

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Tiivistelmä – Referat – Abstract

The thesis examines house price formation in the Helsinki metropolitan area. Especially the price appreciation following financial liberalisation of the late 1980's and the subsequent price decline of the early 1990's recession mark the development of house prices. During the 2000's house prices have increased rapidly with the exception of the slump during the financial crisis. This thesis focuses on explaining the aforementioned development with emphasis on the long-run aspect in both theoretical and empirical examinations. The primary goal is in studying long-run interdependence between house prices and fundamental determinants mentioned in theoretical and empirical literature. Based on the achieved results it is possible to draw conclusions on the sustainability of the price level as well as study the effects of various fundamentals on the metropolitan area price level.

The thesis is separated into a theoretical and an empirical section which makes use of econometric methods in modelling house prices. The long-run relationship between house prices and selected fundamental variables is examined using cointegration analysis. The fundamentals and house prices are modelled in a vector error correction framework central to cointegration analysis. Alongside house prices, household disposable income, mortgage interest rates, metropolitan area total net migration and the stock of housing loans describing household indebtedness are introduced into the system. The quarterly data are compiled from Statistics Finland and Bank of Finland databases for the time period 1983–2012.

The central result of the thesis is a long-run equilibrium model between house prices and the fundamental determinants. The model is found to work satisfactorily as the results accord with theory and the results are statistically significant. In addition, the results are in line with previous empirical studies conducted in Finland. Furthermore it is discovered that mortgage interest rates, household indebtedness and migration patterns have been notable factors in determining house prices, especially towards the end of the examination period. The achieved results on short-run dynamics also provide support to the estimated long-run model. A key finding considering the short-run dynamics is the sluggish adjustment of house prices towards their long-run level.

Based on the results of this thesis, house prices in the Helsinki metropolitan area have exceeded the estimated long-run equilibrium price level for a prolonged period. This phenomenon can be explained by demand side factors including high net migration to the region as well as low mortgage rates encouraging mortgage lending. On the other hand, inelastic supply and scarcity of land specific to urban areas restrain the rapid unravelling of excess demand in the housing market. It is thus possible, that in the future house prices will adjust downward toward their long-run equilibrium level.

Avainsanat – Nyckelord – Keywords
House prices, cointegration, error correction

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UNIVERSITY OF HELSINKI

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Lauri Saarinen

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Tiivistelmä – Referat – Abstract

Pro gradu -tutkielma tarkastelee asuntojen hintojen muodostumista pääkaupunkiseudulla. Erityisesti Suomen rahoitusmarkkinoiden vapautumista seurannut hintatason nousu 1980-luvun lopulla sekä 1990-luvun alun laman aikainen hintojen lasku leimaavat hintakehitystä. Asuntojen hinnat ovat nousseet vauhdikkaasti 2000-luvun puolella, lukuun ottamatta finanssikriisin aikaista hintatason notkahdusta. Tämä tutkielma keskittyy selittämään kuvattua kehitystä keskittyen pitkän aikavälin tarkasteluihin niin asuntojen hintojen muodostumisen teorian kuin empiiristen tarkastelujen osalta. Työn ensisijainen tavoite on tutkia pitkän aikavälin riippuvuussuhteita asuntojen hintojen sekä teorian mukaisten fundamentaalisten muuttujien välillä. Saatujen tulosten avulla on mahdollista tehdä johtopäätöksiä hintatason kestävyydestä sekä eri tekijöiden vaikutuksista pääkaupunkiseudun asuntojen yleiseen hintatasoon.

Tutkielma jakaantuu teoreettiseen tarkasteluun sekä empiiriseen osioon, joka hyödyntää ekonometrisiä menetelmiä asuntojen hintojen mallintamisessa. Tutkimuksessa tarkastellaan asuntohintojen ja muiden muuttujien välistä pitkän aikavälin tasapainoriippuvuutta eli niin sanottua yhteisintegroituvuutta. Keskeisenä ekonometrisenä menetelmänä tutkimuksessa muotoillaan ja estimoidaan asuntojen hintojen sekä muiden muuttujien välistä käyttäytymistä kuvaava vektorivirheenkorjausmalli. Asuntojen hintojen ohella muita analysoitavia muuttujia ovat kotitalouksien käytettävissä olevat tulot, asuntoluottojen korot, pääkaupunkiseudun kokonaisnettomuutto sekä kotitalouksien velkaantumista kuvaava asuntoluottojen kanta. Käytetty aineisto on koottu Tilastokeskuksen ja Suomen Pankin aineistosta ja sisältää neljännesvuosittaiset aikasarjat edellä mainituista muuttujista aikavälillä 1983–2012.

Tärkeimpänä tuloksena saadaan pitkän aikavälin riippuvuussuhde pääkaupunkiseudun asuntojen hintojen ja edellä mainittujen muuttujien välille. Mallin havaitaan toimivan hyvin, sillä tulokset ovat teorian mukaisia ja tilastollisesti merkitseviä. Tulokset ovat myös pääpiirteittäin linjassa aiempien Suomessa tehtyjen tutkimusten kanssa. Jatkotarkastelussa havaitaan erityisesti asuntoluottojen korkojen, asuntoluottokannan sekä muuttoliikkeen olleen merkitseviä tekijöitä hintojen määräytymisessä etenkin tutkimusperiodin loppuvaiheessa. Lyhyen aikavälin hintadynamiikkaa koskevat tulokset tukevat osaltaan estimoitua pitkän aikavälin tasapainorelaatiota. Tärkeimpänä lyhyen aikavälin dynamiikkaa koskevana löydöksenä voidaan pitää havaittua asuntojen hintojen hidasta sopeutumista estimoidun pitkän aikavälin mallin mukaiseen tasoon.

Tulosten perusteella pääkaupunkiseudun asuntojen hinnat ovat olleet tutkielman kirjoitushetkellä jo pitkään estimoidun pitkän aikavälin riippuvuussuhteen mukaista tasoa korkeammalla. Ilmiön voidaan todeta johtuvan kysyntäpuolen tekijöistä, joihin lukeutuvat vahva muuttoliike seudulle sekä luotonottoon kannustava alhainen korkotaso. Toisaalta kaupunkialueille ominainen pula tonttimaasta yhdistettynä tuotannon jäykkyyteen estää liikakysyntätilanteen nopean purkautumisen. On näin ollen mahdollista, että tulevaisuudessa asuntojen hinnat sopeutuvat alaspäin kohti pitkän aikavälin tasapainoa.

Avainsanat – Nyckelord – Keywords
Asuntojen hinnat, yhteisintegroituvuus, virheenkorjausmalli

Contents

1 Introduction

Over the past three decades price fluctuations in the Finnish housing markets have been very significant. In the Helsinki Metropolitan Area (HMA)[1] real house prices rose by 66 percent between the final quarter of 1986 and the first quarter of 1989. In the housing market literature this housing price bubble has been associated with the deregulation of Finnish financial markets which eased bank lending constraints and lead to higher household debt. Low real interest rates and favourable tax conditions for owner occupied housing also contributed to rising house prices. Similarly, a rapid decline in the housing markets was recorded from the peak of 1989 to the final quarter of 1992, as real prices plummeted 57 percent. This collapse has in turn, been associated to the severe recession that hit the Finnish economy in the early 1990's which prolonged the stagnation in the housing markets. Large scale unemployment combined with tightened bank lending and rising real interest rates as well as tax reforms had the effect of pushing down housing demand and prices. Despite these fluctuations real house prices in the HMA have risen by 99 percent between 1983 and the end of 2012.

This thesis is an attempt on explaining these housing price patterns in the period 1983 to 2012 by means of econometric analysis. As housing markets are highly regional in nature, the analysis is restricted to the HMA. For example, Oikarinen (2007, 12) notes that regional housing price development in Finland has diverged extensively since the early 1990's due to increased migration from peripheral to central areas. Previous studies have determined a wide range of fundamental economic factors underlying house price fluctuations in the long-run. These fundamental factors include household incomes, bank lending, constructions costs, demographics, real interest rates and tax treatment of owner-occupied housing

[1]The Helsinki Metropolitan Area consists of Espoo, Helsinki, Kauniainen and Vantaa.

to mention a few. In this thesis, the main focus is on analysing the long-run determinants of housing prices and on constructing a long-run equilibrium model. The model will also be used to the analysis of short-run dynamics and can be used to draw conclusions on the sustainability of recent house price developments in the HMA.

The thesis will begin with a brief introduction to the characteristics of the markets for housing and the significance of housing markets to the macroeconomy. Specific characteristics and recent history of the Finnish and the HMA housing markets are also presented. The section finishes with a look into demographic changes which have affected the housing markets and trends in housing production. In the second section theoretical models of house price formation are reviewed. The section ends with a remark on empirical application. The third section surveys recent housing market studies focusing especially on the estimated long-run relationship between house prices and fundamentals. Short-run price dynamics are also reviewed. The next section introduces the research methodology. Section five presents and discusses the data. The empirical results are presented and discussed in section six. The final section summarises the main findings and concludes.

2 Introduction to the housing markets

This section begins with an introduction to the housing market and more particularly on what separates the housing market from markets for other goods and services. The macroeconomic implications of the housing markets will be discussed right after. Next, the key developments and institutional changes of HMA and Finnish housing markets from the previous three decades are covered. The section is finished with a brief look into the metropolitan area demographic changes which have undoubtedly influenced the HMA housing markets.

2.1 Housing market characteristics

The operation of housing markets differs significantly from other markets for goods and services. Housing is in itself consumed by households as any other good or service, but notably dwellings can simultaneously form a major part of household wealth. Laakso & Loikkanen (2004) review some of the characteristics of the housing markets. First of all, housing is a necessity and very often fixed to a location. This obviously does not imply the ownership of a dwelling as renting is an option. Housing is also a particularly expensive good. The market price of a medium sized dwelling is approximately fourfold the income of an average household in Finland (Laakso & Loikkanen 2004, 251). Third, housing is a heterogeneous good as a particular dwelling is a combination of structural, quantitative and qualitative characteristics. For example, the surrounding environment is of importance when the choice of dwelling is made. In addition, it is not only the dwellings that are heterogeneous but also the households demanding housing services vary in their characteristics, income and preferences.

Another characteristic of the housing markets are high transaction costs related to search, migration, taxation and other costs. Because of these high transaction costs, households move from a dwelling to another relatively rarely. High informational asymmetry is also a feature of the housing market. The seller is presumably more aware of the true characteristics of the dwelling than the buyer. Potential buyers have to evaluate the market value of a particular dwelling with respect to sales made in the nearby area which poses difficulties due to the heterogeneity of housing.

As noted above, households have a choice when consuming housing services: typically the choice is between owner-occupied and market rental dwellings. In both cases the household occupying the dwelling consumes the housing service. However, in the case of owner-occupancy, the dwelling forms a part of the residents' stock of wealth. The household then receives return from ownership and bears costs of housing and risk from possible future price and cost fluctuations. In case of rental dwellings, the household simply receives a housing service and pays compensation to the owner in the form of rent. The owner carries risk and other costs as in the case of owner-occupied housing.

Finally, housing is a particularly long-term consumption good. The planning and construction period of new dwellings is approximately two years at the shortest. In addition, the production of new dwellings is low compared to the existing stock of dwellings, varying between 1-3 % per annum (Laakso & Loikkanen 2004, 252). This implies that a large portion of the housing supply consists of existing dwellings, further implying that households occupy the housing markets as both buyers and sellers. Thus, housing supply is inelastic in nature and house prices may be significantly autocorrelated at least in the short to medium run. As some of the above suggests, the housing markets are of macroeconomic importance. The necessity of housing and the high cost of housing consumption alone cause housing markets to affect the whole economy.

2.2 Housing markets and the macroeconomy

Oikarinen (2007) reviews key interdependencies of the housing market and the macroeconomy. First, for the reason that housing is an expensive good and dwellings comprise the majority of many households' wealth, changes in house prices have major implications for household consumption. For example, in 2005 approximately 29 % of Finland's national wealth was tied in residential buildings. Altogether all buildings and constructs accounted for nearly 60 % of the national wealth (Niemi & Sandström 2007). Benjamin et al. (2004) study the high concentration of household wealth in housing rather than in financial assets in the United States. They find that the marginal propensity to consume from housing wealth exceeds that for financial assets. Case, Quigley & Shiller (2001) find for their international sample that propensity to consume from housing wealth varies between 11 and 17 cents per dollar of wealth for each additional dollar of wealth, whereas the corresponding figures for financial wealth are between zero and two cents. Thus, fluctuations in house prices and housing wealth have significant effects on total consumption.

Second, falling housing price level has a negative impact on the housing construction, which in turns has a negative impact on output and employment. Third, housing price developments have considerable effects on the financial sector. There is a clear link between house prices and bank lending as banks relax lending constraints when house prices are high. Similarly, a dip in housing prices causes losses on mortgage lenders which can cause a negative shock for the financial system. Goodhart & Hoffman (2007) note that houses are often used as collateral for loans and thus a large share of financial sector assets are tied to housing values. Therefore housing price fluctuations can have major impacts on economic activity and the soundness of the financial sector as was shown in the event of the financial crisis of 2007-2009.

2.3 The Finnish and the Helsinki Metropolitan Area housing market developments

In 2012 the total Finnish stock of housing was approximately 2,556,000 dwellings.[2] Owner-occupied housing accounted for about 65 % of the stock of dwellings. Rental dwellings accounted for 30 %. About 1.4 % consisted of right of occupancy dwellings which is a specific tenure status introduced to the Finnish housing markets in the early 1990's to promote the supply of reasonably priced dwellings. According to Oikarinen (2007, 57) institutional investors (inc. the public sector) own approximately one half of the stock of rental dwellings. In the HMA, the composition of the housing stock differs from the national stock. In 2011, owner-occupied dwellings accounted for 52.6 %, rental dwellings for 42 % and right of occupancy dwellings for 3 % of total housing stock in the HMA. The share of rental dwellings of the total stock decreased until the early 1990's. After a brief period of increase, the share of rental dwellings has further decreased from the late 1990's onward (Laakso & Loikkanen 2004, 248). Nevertheless, the share of rental dwellings compared to owner-occupancy differs notably between the HMA and the rest of the country. In addition, the share of multi-storey housing companies of the total stock is higher in the HMA than in the rest of the country.

[2]Source: Statistics Finland (a)

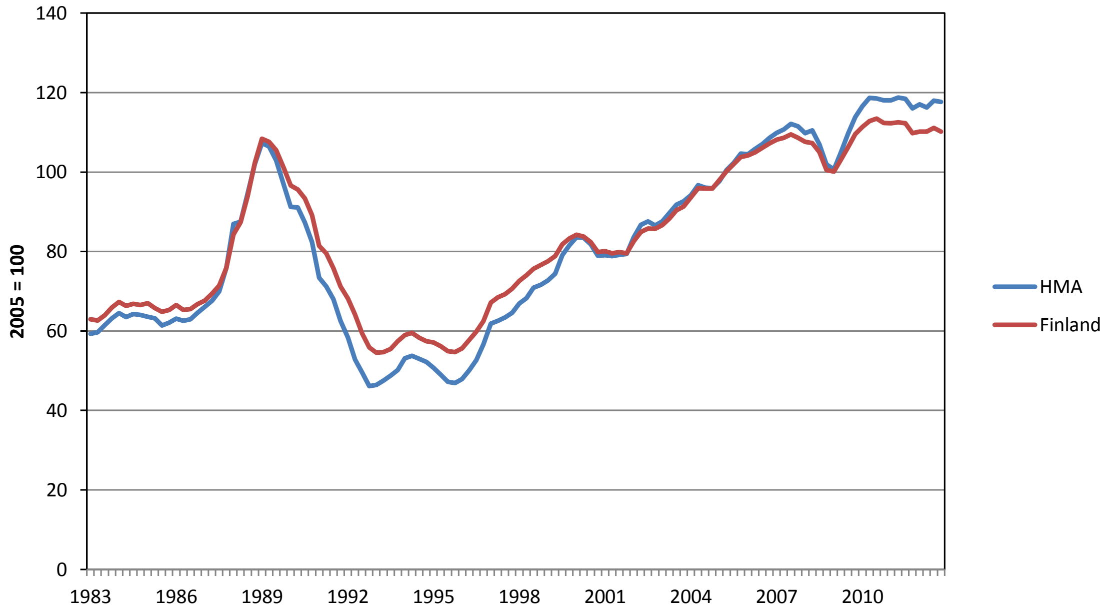

Figure 1: Real house prices in the HMA and in Finland 1983Q1-2012Q4 (Source: Statistics Finland)

Figure 1 depicts the development of real house prices in the HMA and in Finland from 1983 onward. The indices describe the evolution of the price of old dwellings from 1983 to present.[3] The two years of relatively stable real prices from 1984 to 1986 were followed by a period of rapid growth which lasted until the third quarter of 1989. This period of rapid house price growth is generally associated with the deregulation of the Finnish financial markets. Until the mid-1980's bank lending was strictly controlled along with foreign capital controls which lead to credit rationing. In 1986 the Bank of Finland deregulated the banking system and ceilings on lending rates were abolished. This improved the accessibility to mortgages, especially as down payment ratios were relaxed. Deregulation rapidly increased bank lending and caused a housing market boom.

The housing bubble burst at the end of 1989. Real prices declined until the end

[3]Section six presents a more precise description of the data

of 1992. In 1993 real housing prices were lower than in 1986 in the whole country. The fall in real prices was further deepened by the recession of the Finnish economy in the early 1990's. Kosonen (1997, 2) notes that falling or stagnating household real income and mass unemployment further depressed the demand for housing and accelerated price falls. As mentioned in the previous section, falling house prices negatively impact new construction which reflected back into total output. Increasing real interest rates also discouraged mortgage lending and reduced the demand for owner-occupied housing.

Furthermore, apart from strict regulation of the banking sector until the mid-1980's housing prices in Finland have been affected by rental controls and tax deductibility of interest payments on mortgages. Real rents declined from early 1970's to late 1980's. Rent controls were abandoned in the period 1992-95 and free market rents have increased since.[4] The deductibility of interest payments on mortgages in taxation implies a lower after-tax mortgage rate. This has the effect of increasing demand for housing services. In Finland, interest payments on mortgages were fully tax deductible up to 1974, then until 1992 the interest payments were deductible in income taxation at marginal income tax rate. In 1993 the tax deductibility was further reduced. From then on interest payments multiplied by the capital income tax rate have been deductible. Since 2012, the deductible share has been lowered to 85% and in 2013 to 80% of interest payments. The tendency in tax treatment is clearly moving toward eliminating this tax benefit encountered by mortgage lenders.

After the recession of the early 1990's real prices have increased almost continuously with the exception of the slowdown in 2008-09. Real prices have risen

[4] Removing rent controls should make owner-occupied housing more attractive and may have fed to house prices

faster in the HMA than in the rest of the country both before the housing bubble and after the early 1990's recession. Oikarinen (2007) attributes this to rapid population and income growth in the HMA combined with an inelastic housing supply. Intuitively the supply is more inelastic in HMA than in the rest of the country due to scarcity of available land in urban areas. Zoning policies may also be sluggish to respond to growing housing demand. Therefore, in periods of high demand, short-run equilibrium requires steeper price rises than in areas of more elastic supply. The subsequent fall in real prices is also expected to be steeper in an urban area. Finally, falling inflation has probably influenced real housing prices. Poterba (1984, 734) argues that higher inflation reduces homeowner's user costs because while nominal mortgage interest payments are tax deductible, gains from house price appreciation for the homeowner are effectively untaxed. However, inflation in the case of fixed nominal payment mortgages can reduce the "effective duration" of the mortgage and initial nominal down payment requirements may prove to be restrictive for potential mortgage lenders (2. Ibid., 731).

2.4 Recent demographic developments

In addition to the institutional changes reviewed in the previous subsection, it is useful to review recent demographic patterns in the HMA. Population growth and structure affect the housing market in two main ways. Population growth causes both upward pressure on prices and this leads to an increased housing supply albeit with a lag. Population age structure in turn influences migration patterns which alter regional population growth patterns.

According to Laakso (2000) the size and structure of households and population are key factors in determining housing demand and thus house prices. Furthermore, migration also causes significantly greater fluctuations in the size and structure of population at regional than at national level (Laakso 2000, 28). The main reason for inter-regional variation in population development in Finland in the recent decades has been migration. Mobility to the Helsinki region and other major urban areas has increased from the countryside and smaller towns. In the 1980's population growth in the Helsinki region accelerated due to employment and income growth. Correspondingly the rural areas lost population to urban areas (2. Ibid, 29).

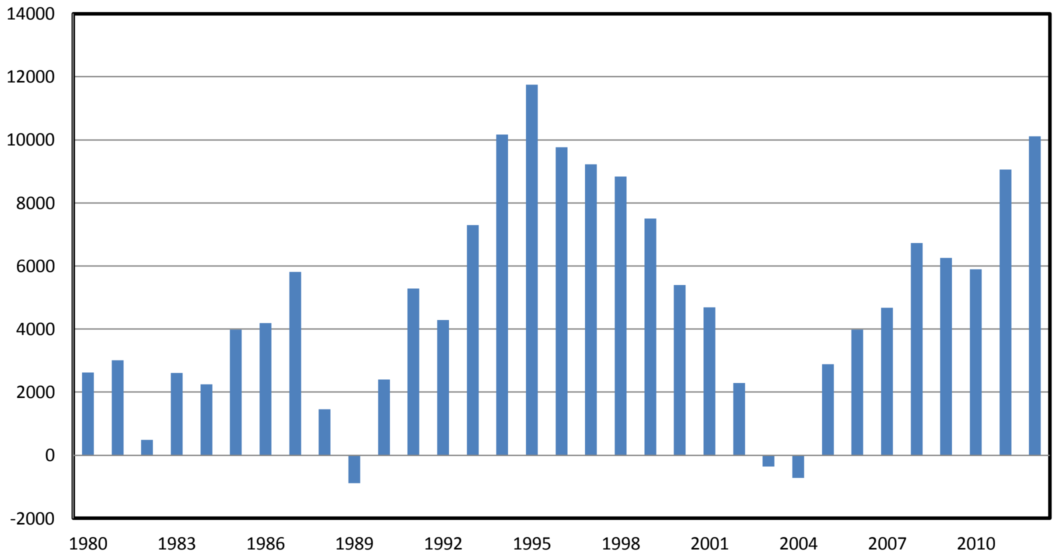

Figure 2: Annual net migration in HMA (Source: Statistics Finland)

The population trend changed in 1988-89, thus slowing down growth in Helsinki region and decelerating the decline in rural areas. Migration from former Soviet Union again shifted the falling population trend in the Helsinki region during the recession era in 1991-93. Statistics show a notable increase in net migration observed in most large urban areas in Finland from 1994 on (see Figure 2). This is largely explained by the introduction of a new home municipality law which came into effect beginning 1994, allowing students to be registered as residents of the municipality in which they studied. Previously they had been registered in the municipality of their parents' home.

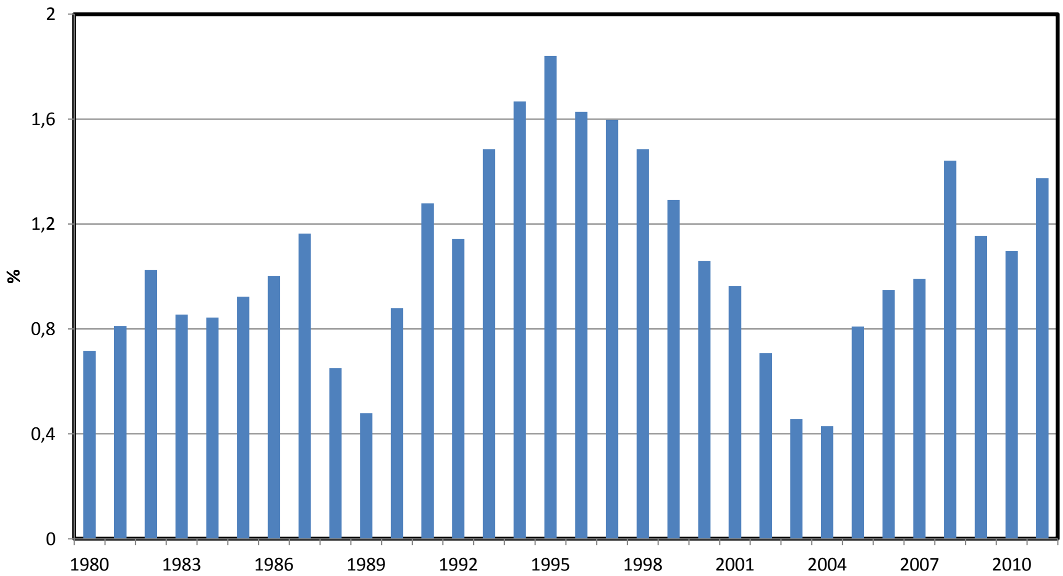

Figure 3: Annual population growth in the HMA (Source: Statistics Finland)

The population growth in HMA was fairly rapid in the late 1990's and the first years of the 2000's. Figure 3 shows that growth slowed down between 2002 and 2004, but accelerated again in the years that followed. Figure 4 in turn shows that the area was actually subject to negative net migration between 2003-05 when considering only Finnish citizens.[5] Nivalainen & Vuori (2012, 162) recognise two main reasons for the negative net migration of Finnish citizens to the area in this period. Firstly, the depression in the technology sector in the early 2000's tested areas with large concentration of employment in the sector such as the HMA. Second, the decline in the rate of population growth for the period is further explained by increased outward migration from the HMA to the so called 'outer labour market area' - or neighbouring municipalities - as a consequence of declining interest rates which allowed especially families with children to con-

[5]Foreign citizens displayed in red, Finnish citizens in blue. Figure from Laakso (2007, 10)

struct affordable one-family housing in these areas. Nevertheless, the impact of these migration patterns on Helsinki and the HMA was short lived as domestic migration to the area increased post-2005 combined with the new coming of foreign in-migration beginning in 2005. In the 2000's total net migration growth in the Helsinki region has actually increasingly been down to foreign citizens and less so down to Finnish citizens as is shown in figure 4.

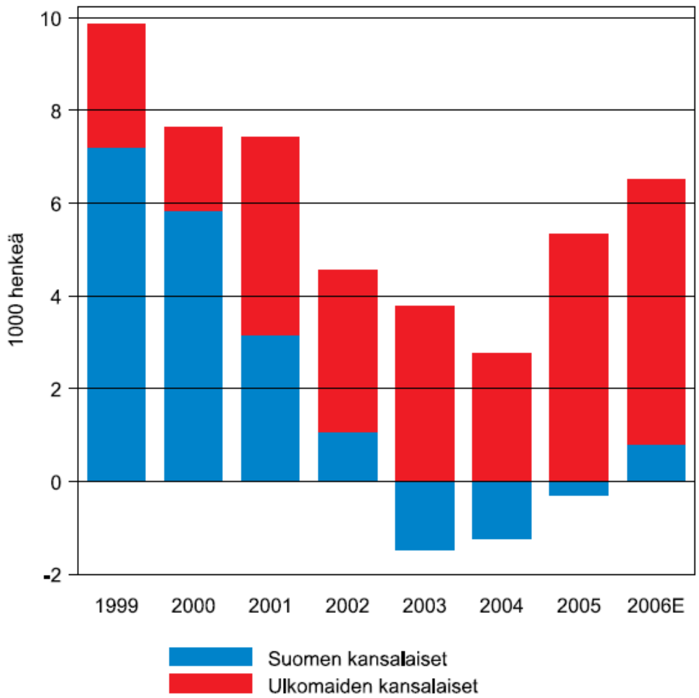

Figure 4: Net migration of Finnish and non-Finnish citizens 1999-2006 (Laakso 2007)

Laakso (2000) emphasizes the role of age structure of population as another key determinant of housing demand alongside population size. Studies by Mankiw & Weil (1989) for US data and Kuismanen et al. (1999) for HMA have shown that housing consumption per capita with respect to age increases most rapidly within the 20 to 29 year-old age group. In context of the housing markets, these studies show the importance of this age group for the housing demand because of the groups' high mobility and because of the groups' rapidly increasing housing consumption (Laakso 2000, 30). The proportion of the population belonging to this age group has decreased throughout Finland since the 1970's due to diminishing generations but meanwhile migration has lead to regional polarisation of this proportion. As the majority of migrants are young adults, then migration surplus areas – such as the HMA – have increased their proportion of young adults at the expense of rural areas since the 1970's. As the age structure in the HMA is still considerably younger than elsewhere in the country, natural population growth is still a considerable factor in the regions' population growth (Laakso 2007, 9). The number of households has also increased faster than population in Finland which has lead to falling average size of households. As there are more households relative to population in urban than in smaller urban or rural areas, the demand for housing relative to population size is higher in urban areas. Reflecting on these issues, it would seem that demographic forces of the recent decades have worked towards increasing demand side pressure on house prices in the HMA.

So far this section has discussed the development of the HMA housing markets and reflected on a number of determinants affecting the demand side factors of housing markets. On the supply side, the HMA annual housing production has averaged around 8000 dwellings from the mid-1980's to mid-2000's. However, production has fallen systematically since the early 2000's and especially in the Helsinki area. Laakso (2007) accounts this especially to supply side factors. First, the role of the Arava-system of state-subsidised funding for housing has diminished considerably as the terms of market based financing have improved since the introduction of the euro and the subsequent fall in interest rates. Supply of Arava–based rental housing has since declined rapidly. Simultaneously free market supply has been combined with fading enthusiasm for interest subsidised rental housing provision by the municipalities, and these supply channels have been unable to compensate for the supply reduction in the Helsinki area which has traditionally been the core region of state supported housing supply. The availability of vacant lots for new construction has also decreased since the 1990's. Vacancy is further undermined because possessors of privately owned sites hold on to land as increasing prices of existing housing stock promote an optimal strategy of refraining from selling in search of higher future returns. Interestingly, empirical literature on housing price dynamics largely neglects the supply side of housing markets because supply side variables are hard to account for in empirical studies or provide little additional explanatory power to empirical models. Potential supply side data include a housing stock variable and real construction cost index, which is most often used in empirical applications.[6]

[6] For additional information, see section 6 and Oikarinen (2007)

3 Theoretical models of house price formation

This section will review two theoretical models of house price formation which have very similar implications for empirical estimation. As housing markets can differ significantly regionally in terms of price level, growth and dynamics, it should be noted that the following models are best thought of in a regional context. A metropolitan area should be a suitable choice as dwellings in HMA can be regarded as relatively close substitutes for each other. The section finishes with a brief motivation for the methodological choice of section five.

3.1 The asset market approach

When attempting to determine a price for a dwelling, it is crucial to calculate correctly the financial return associated with an owner-occupied property. Such a calculation compares the value of living in that property for a year ("imputed rent", or what it would have cost to rent an equivalent property) with the lost income that one would have received if the owner had invested the capital in an alternative investment ("the opportunity cost of capital"). This comparison should take into account differences in risk, tax benefits from owner-occupancy, property taxes, maintenance expenses and any anticipated capital gains from owning the house (Himmelberg et al. 2005, 74). This approach is known as the asset market approach to owner-occupied housing introduced by Poterba (1984). The model allows an economically justified way of assessing whether house prices are too high or too low by comparison of user cost of owning a dwelling to renting. The original article by Poterba (1984) considers only the price of house structures, but the theory can be applied to situations were house price is an entity including the structures and the land. The presentation follows Himmelberg et al. (2005).

The annual cost of homeownership or the "imputed rent" is comprised of six components which represent both costs and offsetting benefits to owner occupancy. First, the homeowner incurs the cost of foregone interest that the homeowner could have earned by investing in something other than a house. The one year cost can be expressed as a multiplication of the price of a house P_t and the risk-free interest rate r_t^{ft}. Next, the one-year cost of property taxes is computed as house price P_t times property tax rate ω_t. Third, an offsetting benefit to owning, namely the tax deductibility of mortgage interest and property tax is introduced. This is estimated as the house price P_t times effective tax rate on income τ_t, multiplied by estimated mortgage and property tax rates r_t^m and ω_t, respectively. In the Finnish case, τ_t should be viewed more broadly as tax benefit of mortgage payments, as the rules of tax deductibility of mortgage rates have changed multiple times in the recent decades and interest on mortgage payments has not been fully deductible after 1974 as discussed in section 2.3. The fourth term is δ_t which reflects depreciation as a share of house value. The term can be thought of as maintenance and repair costs required to retain a constant quality of dwelling structures. Fifth, g_{t+1} is the expected capital gain or loss during a year and finally $P_t\gamma_t$ represents the additional risk premium to compensate homeowners for the higher risk of owning versus renting. The resulting equation for the annual cost of homeownership is

$$\textit{Cost of onwnership} = P_t \cdot r_t^{ft} + P_t \cdot \omega_t - P_t \cdot \tau_t \cdot (r_t^m + \omega_t) + P_t \cdot \delta_t - P_t \cdot g_{t+1} + P_t \cdot \gamma_t \quad (3.1)$$

Oikarinen (2007, 28) notes that in Finland, property tax rate is not tax deductible in the case of owner-occupancy, thus the equation can be simplified and assumed that the term δ_t also includes the property tax. The equation becomes

$$\textit{Cost of onwnership} = P_t \cdot r_t^{ft} - P_t \cdot \tau_t \cdot r_t^m + P_t \cdot \delta_t - P_t \cdot g_{t+1} + P_t \cdot \gamma_t \quad (3.2)$$

Housing market equilibrium requires that expected annual cost of ownership equal the annual cost of renting. Thus, if annual ownership costs rise without corresponding increases in rents, house prices must fall to attract potential buyers to ownership rather than to rent. Obviously, the opposite applies in case ownership costs fall without matching reductions in rental prices. This "no arbitrage" condition then implies that the sum of annual costs of housing must equal annual rent. Equation (3.2) can be used to present this logic and to equate annual rent R_t with the annual cost of ownership

$$R_t = P_t \cdot u_t \tag{3.3}$$

where u_t is the user cost of housing defined as

$$u_t = r_t^{ft} - \tau_t \cdot r_t^m + \delta_t - g_{t+1} + \gamma_t$$

The user cost of housing is just the annual cost of ownership *per dollar of house value.* Again, rearranging gives $P_t/R_t = 1/u_t$, which states that the equilibrium price-to-rent ratio should equal the inverse of user cost. Then, fluctuations in the user cost lead to predictable changes in the price-to-rent ratio that reflect changes in fundamental determinants. Comparing price-to-rent ratios over time does not provide information about over- or undervaluation if user costs are not taken into account in such an evaluation.

The role of inflation is key to house prices. As noted in the previous section, higher inflation rates reduce homeowners' user costs because while nominal mortgage interest payments are tax deductible, the capital gains from house appreciation are essentially untaxed (Poterba 1984, 734-5). This implies that an increase in the rate of inflation, holding housing stock constant, increases real house prices. However, inflation works in the opposite direction as well. Rising inflation raises nominal interest rates, which implies a real rise in repayment of a usual annuity mortgage in the early years of the loan. Tighter liquidity constraints in the beginning of the lending period reduce demand for housing and depress house prices.

Real interest rate is also an important determinant for user cost of housing. A lower real interest rate reduces the cost of a mortgage and simultaneously lowers the opportunity cost of residential investment. As mortgage interest is tax-deductible and the opportunity cost of the equity in the house is taxable return, a percentage point fall in real interest rate reduces the user cost by $1 - \tau$ (Himmelberg et al. 2005, 76). The user cost formula also implies that a percentage point decrease in real interest rates in a low interest rate environment causes a larger percentage increase in real house prices than a similar percentage point decrease would in a high real interest rate environment.[7] As with real interest rates, a higher income tax rate - when applicable - lowers the user cost of housing as higher income taxation raises the tax-subsidy to owner-occupied housing. The effect should be more pronounced for high tax rate households as their marginal costs for housing also change the most (Poterba 1991, 152).

A metropolitan area where expected house price appreciation (expected inflation and real expected appreciation rate of housing) is high has a lower user cost than an area where expected appreciation is low. Himmelberg et al. (2005, 78) note that if the long-run supply of housing were perfectly elastic, then house prices would be determined solely by construction costs and expected appreciation would be determined by expected growth in real construction costs. However, the long-run growth of house prices has historically exceeded growth in construction costs. This suggests that land value is appreciating faster than the value of

[7] Empirical studies report an average sensitivity of house prices to interest rate changes, as it is difficult to account for different interest rate regimes.

structures. This is no surprise as especially in densely populated urban areas land is in short supply, so demand growth capitalises into land prices.

3.2 The present value approach

The present value condition is very similar to the user cost view presented in the previous section. The main idea behind the present value approach is that the price of housing is the present discounted value of future net housing services. Equation (3.3) of the previous subsection can be used to form an asset price formula to describe the present value of housing.

$$P_t = E_t \sum_{t=1}^{h} \left[\frac{R_t - \delta_t + \tau_t \cdot r_t^m}{(1 + \theta_{t,t+\eta})^\eta} \right] + E_t \left[\frac{P_h}{(1+\theta)^h} \right] \tag{3.4}$$

where P_t is the price of a dwelling at time t and E_t is the expectations operator. $\theta_{t,t+\eta}$ denotes the required rate of return from time t to η and h is the length of the planned investment horizon. The risk premium (γ_t) and the risk-free rate (r_t^{ft}) are incorporated in θ. In this formulation δ_t and r_t^m refer to absolute values of depreciation and mortgage payment.[8] The present value formula as presented in (3.4) consists of two components: the expected net rental capital income (implicit rents) and expected house price appreciation. The analogy is the same as in financial assets such as shares where total yield is composed of dividends and price appreciation.

In empirical applications measurement problems arise with both methods as problems of evaluation of expected appreciation and rate of return still remain. It is equally challenging to determine appropriate values for depreciation of a structure, not to mention the risk premium which also enters the formula. In many

[8] This manner of representation follows Oikarinen (2007)

studies households' expected growth rate of house prices is proxied with average past price growth rates or just estimated from past or present values of fundamental determinants. This implies backward-looking expectations which are problematic when attempting to assess current prices.[9] In some studies, simple price-to-income (P_t/Y_t) and price-to-rent (P_t/R_t) ratios are applied to study house price valuation. An obvious fault in the former is that there are other factors apart from real incomes that affect the housing price level and thus there is no valid reason for why this ratio should return to a fundamental level. As prices and rents are more interlinked, the (P_t/R_t) ratio should be more suitable for examination over time. However, structural changes such as rental market deregulation can cause challenges in rent-price comparison over time. For these and other reasons (see Oikarinen 2007, 121-3) the study of these simple ratios is omitted in this thesis.

Aside these problems, the empirical model that can be derived from the theory of this section is one where the unobservable real rental price of the flow of housing services (R_t) is proxied by the determinants of the demand and supply of housing services (Holly & Jones 1997, 554). From the theoretical discussion of this section we should expect that these determinants include some measures of income, demographics, the housing stock and user cost. The motivation for the choice of determinants is provided in section six. The methodology that has been adopted in many of the more recent studies has been cointegration analysis which allows for testing of one or more long-run relationships between variables put forward by economic theory. Cointegration analysis also provides information on housing price dynamics. For these reasons, cointegration is applied in the empirical section of this thesis.

[9] A more comprehensive review of the measurement challenges of user cost can be found in Himmelberg et al. (2005, 79-82)

4 Studies on house price dynamics

Most of the empirical research in the field of housing price dynamics concentrates on two major issues. First, most studies estimate a long-run equilibrium price level. Often estimation results are compared with actual price dynamics to draw conclusions on the possible under- or overvaluation of house prices in specific periods. Secondly, studies analyse the short-run dynamic adjustment of house prices after deviations from long-run equilibrium. In more recent studies the methodology used is often cointegration analysis. Most studies acknowledge a long-run relation towards which house prices adjust and find adjustment sluggish. Similarly, there seems to be widespread consensus on the determinants of house prices. However, there are large differences in empirical results largely due to imperfect data and because housing markets have region-specific features. This chapter reviews a selection of studies from the recent decades.

As discussed in the previous section, the user cost formula implies that the price per unit of housing services is the user cost per dollar of house value multiplied by the price level of houses. Then a change in the user cost per dollar of house value should leave the cost of housing services unaffected and be offset by a proportionate change in house prices. Thus, the elasticity of house price with respect to per unit user cost should theoretically be equal to one. Then, building a regression with house prices as a dependent variable and supply, user cost and possibly other demand side variables as explanatory variables should provide estimates for the price, income and other (long-run) elasticities. Since the supply side is harder to measure, it is often omitted or replaced with an 'indirect' measure of supply such as construction cost index in empirical applications.

4.1 House prices and fundamentals

Most housing price studies find a statistically significant positive relationship between house prices and some measure of disposable income or GDP. Noting that although income as such does not enter the theoretical models of the previous section, it is almost always included in studies. Englund (2011, 43-44) argues that since income is a major determinant of housing consumption and since supply is constrained by scarcity of land, one would expect a close relationship between household disposable income and house prices. Girouard et al. (2006) review a large selection of studies conducted mainly in European countries or the U.S. The panel studies and regional studies find elasticities of real house prices relative to real disposable income reaching from as low as 0.1 to 0.2 for Ireland (McQuinn 2004) to 8.3 for Parisian markets (Bessone et al. 2005). Most of the studies reviewed use an error-correction model to analyse price dynamics. Case & Shiller (2003) use a rare methodology in the field of housing price studies as they conduct a questionnaire survey for homebuyers in four U.S. metropolitan areas in 2002. They find that for more than forty U.S. states income growth alone explains almost all of the house price increase, however they find evidence for the existence of a speculative bubble in some cities as well.

Some of the pioneering work on econometric house price modelling is introduced in Hendry (1984). The ADL model specification is set up between average house price to household income ratio, loan to income ratio, real income per household, inflation and after-tax interest rates. All coefficients have the expected sign. Abraham & Hendershott (1996) employ a regression model to explain cross-sectional annual variation in real house price movements in 30 U.S. cities over the 1972-92 period. In the model real house appreciation is explained by changes in the equilibrium price and adjustment dynamics including lagged real appreciation and the difference between actual and equilibrium real house price levels. Their model explains three-fifths of the variation in real housing price movements. Mankiw & Weil (1989) introduce a 'demographic demand' variable in their regression to capture housing demand. They report for a sample period reaching from 1947 to 1987 for U.S. data that a one percent increase in demand for housing leads to a sizable 5.3 % increase in the real price of housing. Based on these results the authors forecast that real house prices will fall by 47 % between 1987 and 2007 based on demographic development (that is, falling U.S. birth rates). They also include a real GNP variable in their house price regressions and find long-run elasticities of house prices relative to income ranging from 0.23 to 0.26.

Hort (1998) uses a panel error-correction framework for Swedish data. She analyses a panel of 20 regional housing markets during the period 1970-1994. The four reported specifications yield estimates of real house price elasticity with respect to real income between 0.37 and 0.97. Similarly, estimated elasticity to real construction costs ranges from 0.27 to 0.58. Impact of an increase in the user cost variable also has the expected negative sign, and a percentage point increase in real user cost lowers real house prices by 2-3 %. Capozza et al. (2002) use panel data for 62 U.S. metropolitan areas from 1979 to 1995. They model equilibrium real house prices as a function of the size of the metropolitan area (population level and real median income), the real construction costs, an expected growth premium and the user cost of owner-occupied housing. All variables in the model have the expected sign. They find a long-run income elasticity of 0.43 in the U.S. metropolitan areas. For the long-run effect of a percentage point increase in real interest rate their estimates of the negative effect on house prices vary between 4 and 9 %. Capozza et al. (2002) also report a long-run construction cost elasticity of 1.2 which is fairly high considering urban areas where land accounts for a sizeable portion of the house price.

Meese & Wallace (2003) survey house price dynamics in Paris using monthly transaction-level data for the period 1986 to 1992. They estimate an error-correction model with prices, a construction cost variable, the cost of capital, employment and real income. They find a long-run income elasticity of 0.65 and estimate that a percentage point increase in real after-tax interest rate leads to a 7 % fall in real house prices. Meese & Wallace (2003) find a long-run construction cost elasticity of up to 6.5 which seems overly high. Moreover, the length of the time period considered is very short for a housing market study. Holly & Jones (1997) use a particularly long data set from 1939 to 1994 of annual observations for the UK. They model real house prices with cointegration analysis using real income, demography, interest rate, the housing stock and other variables and find that the most important determinant of real house prices has been real income. Hofmann (2004) uses a cointegrating VAR to analyse determinants of bank credit to the private non-financial sector in 16 industrialised countries including Finland. For Finland, Hofmann (2004) finds elasticity of real house prices with respect to real GDP equal to 0.3. Similarly, for a credit-to-GDP ratio he finds an elasticity of 0.6 with respect to prices. The estimated effect of a percentage point change in real interest rates is a mere 0.5 % in real house prices, which is low compared to other studies. Borowiecki (2009) uses a VAR framework to study Swiss house prices between 1991-2007 and finds that real house prices are most sensitive to changes in population and construction costs. A 1 % increase in population aged 20 to 64 increases house prices by 2 %. An appreciation in construction costs leads to roughly similar increase in house prices. GDP turned out to have limited explanatory power which may be explained by the specification employed.

Hilbers et al. (2008) use a yearly panel of 16 European countries between 1985 and 2006 to estimate house price equations. They split the data into three groups based on the rate of house price appreciation during the sample period. For the 'fast lane' group they find that a percentage point increase in per capita output raises house prices by 2.5 % which is three times more than for the slow growth group. They report similar stronger effects for the fast lane group for a demographic variable, however the estimates have an unexpected negative effect and are partially insignificant. Ganoulis & Giuliodori (2010) estimate a panel error-correction model for a sample of European countries over the period 1970-2004. In the long-run, the elasticity of real house prices with respect to real income is found to lie between 0.9 and 1.5. Estimates of the semi-elasticity with respect to interest rates range from -1.2 to -2.6. They also find that mortgage debt enters the long-run relation albeit with a lower elasticity of approximately 0.3. Ganoulis & Giuliodori (2010) split the sample to check for the effects of financial liberalisation to find that the impulse effect of interest rates on house prices has strengthened post-liberalisation and the effect of income and mortgage debt has weakened.

Adams & Füss (2010) construct a panel error-correction model for quarterly data for 15 OECD countries between 1975-2007. They set up an economic activity measure, which is composed of real money supply, real consumption, real industrial production, real GDP and employment. In addition to the economic activity variable, long-term interest rates and construction costs are added to the model. The results indicate that the elasticity of house prices with respect to economic activity is on average 0.34 for the panel group. For interest rates they find a coefficient of -0.4 and the estimate for construction costs is 1.3.

Research of house price dynamics in the Finnish and HMA markets is quite limited. Kuismanen et al. (1999) use the approach introduced by Mankiw & Weil (1989). They regress real housing prices for the HMA for the period 1962-1997 on a demographic housing demand variable, a one period lagged real income variable and others. They find that the long-run income elasticity of housing price level is 0.81. Kosonen (1997) uses a methodology similar to Abraham & Hendershott (1996) and uses quarterly data for Finland between 1979-1995. The ADL model between real house prices, real disposable income and real after-tax interest rates yields a long-run elasticity of real house prices with respect to income of approximately 1.4. Similarly, a one percentage point decrease in the real after-tax interest rate increases real house prices by 9 % in the long-run equation. Barot & Takala (1998) set up a model to find house prices and inflation cointegrated implying stationary real house prices in Finland and Sweden. The authors admit that the cointegrating relationship may seem puzzling, but find significant evidence.

Laakso (2000) employs annual panel data for 85 Finnish sub-regions from 1983 to 1997. The price model specification follows Abraham & Hendershott (1996). The growth in equilibrium real housing prices in a specific region or city is a linear function of the growth in real construction costs, real income per working age adult, change in employment, vacancy rates and the change in real after-tax real interest rates. Variables related to local demography are left out as they do not add to the explanatory power when used with jobs and income. The estimation results suggest that income and employment variables are positive and significant. Real after-tax interest rate and the lagged vacancy rate have a strong negative effect on real housing prices. The study also finds that basic trends of housing markets were very similar in all regions in Finland during 1980's and 1990's. Laakso (2000, 63) distinguishes a straight forward solution to this phenomenon:

> "... the most crucial external effects on housing markets – changes in interest rates, taxation rules, and income, employment and inflation development - took place at national level and were transmitted to all local housing markets approximately at the same time. Only years after the depression, from 1997 on, there seem to have appeared clear deviations between regions with respect to housing market developments: This is a consequence of recently increasing polarisation of regional employment and population development."

Oikarinen (2007) estimates a cointegrating long-run model between real house prices, real aggregate income, a loan-to-GDP variable and real after-tax lending rate using quarterly observations between 1975-2006 in the HMA. The real aggregate income variable thus includes the effect of population growth on house prices. The study finds that the combination of real disposable income growth and population growth combined with loosening liquidity constraints have increased long-run equilibrium housing prices in the area. Results indicate that a one percent increase in real disposable income raises real house prices by approximately 0.4 %. Similarly, a percentage increase in the loan stock variable reflecting loosening liquidity constraints would yield a 0.5 % increase in house prices. Somewhat surprisingly the real interest rate is not significant in the model. The model finds no evidence for substantial overpricing in the HMA market in 2006. For Finnish national-level data, Adams & Füss (2010) find a 0.78 house price elasticity with respect to their economic activity variable. Similarly to Oikarinen (2007) they find the interest rate variable not significant for long-term house prices. A percentage increase in construction costs feeds a 0.93 % rise in house prices in the long-run in their estimation.

To sum up evidence from these studies, there is strong evidence that house prices are increasing functions of income, population growth and loosening credit constraints. Similarly, higher real after-tax interest rate which also tracks user cost has a significant negative impact on real house prices in most studies. On average, the income elasticity of house prices is around one, though there is a lot of variation in results. According to Englund (2011, 45) this implies that in order to meet the growing housing demand, the housing stock would have to grow at the same rate as income is growing in a society. Otherwise, house prices will have to rise to guarantee a balance between demand and supply. Even though only a few results for the Finnish markets were reviewed some thoughts can be weighed in. It would seem that older studies like Kosonen (1997) and Laakso (2000) find stronger effects of income and interest rate variables on real house prices than the more recent studies by Oikarinen (2007) and Adams & Füss (2010). The observation of long-run *de-linking* of house prices and income seems somewhat surprising as international studies find no evidence of changes in the long-run relation over time.[10] The results on the semi-elasticities of house prices with respect to real interest rates seem equally confusing. As argued in the previous section, Himmelberg et al. (2005) suggested stronger effects of real interest rates on real house prices in a low interest rate environment. However, the aforementioned recent studies on Finnish and the HMA housing markets find very moderate effects of interest rates on house prices despite the fact that the interest rate environment is notably lower when compared to the data period considered in the older studies.

[10]See for example Ganoulis & Giuliodori (2010) who split the sample period to pre- and post financial liberalisation periods.

4.2 Short-run dynamics

Short-run price movements can deviate from the long-run trends for at least three reasons: supply inertia, expectations formation and credit constraints. Therefore, we should expect cyclicality of house prices in the short to medium-run, but in the long-run housing supply should lead prices towards an equilibrium level determined by fundamentals (Englund 2011, 49). This reasoning is behind the use of the error-correction models in a majority of studies. Some results concerning adjustment dynamics are reviewed below. A connective factor to almost all the studies is that they find adjustment in the housing markets sluggish.

Holly & Jones (1997) find that the dynamic adjustment of house prices has been asymmetric depending on whether house prices are above or below their long-run path: adjustment to long-run equilibrium is faster, if prices are above their long-run level. Hort (1998) finds for Swedish data that the speed of adjustment is as fast as 84 % per annum towards the long-run equilibrium. In their analysis, Capozza et al. (2002) find slow adjustment towards fundamental house price level after occurrence of shocks: actual prices converge only 25 % towards the fundamental level every year. Dipasquale & Wheaton (1994) find that prices converge 29 % per year in their backward-looking expectations specification and in their rational forecast model for U.S. data, the rate of price adjustment is just 16 %. Meese & Wallace (2003) find the speed of dwelling price adjustment to be 30 percent per month for the period 1986-1992 using monthly data. Comparing this to, for example, the results of Dipasquale & Wheaton (1994), the difference in the rate of convergence to the long-run price level is striking. Wilhelmsson (2008) utilises panel data for Sweden and finds that depending on the region, the speed of adjustment toward the equilibrium varies between 16 % and 78 %. He also finds that the rate of convergence is negatively correlated with population density. Even more interesting is the finding that house prices converge toward equilibrium faster in an economic upturn compared to a slowdown where it can take 5-6 years before prices adjust. This result is contrary to the findings of Holly & Jones (1997) for UK housing markets. Finally, Adams & Füss (2010) find for the panel of 15 OECD countries a very sluggish adjustment speed of 4 % per quarter implying that half of the equilibrium gap remains after 17 quarters.

For the Finnish markets, evidence points toward equally sluggish adjustment. Pere & Takala (1991) find cointegration between Finnish house and stock prices and estimate an error-correction model for quarterly observations between 1970-1990. The analysis for national level data indicates that the speed of adjustment is 6.9 % per quarter towards the long-run fundamental level. The error-correction model introduced by Kosonen (1997) implies that approximately 15 % of the deviation between current prices and equilibrium prices is removed within a quarter. Oikarinen (2007) finds that less than 10 % of the deviation between the actual price level and the estimated long-run relation disappears within a quarter due to house price adjustment.

The above review suggests that variation in results is equally great for short-run dynamics in housing markets. This paper will adopt the cointegration approach used in most studies to analyse the existence of a long-run relation for real dwelling prices and fundamentals in the HMA. Further, an error-correction model will be utilised to study short-run dynamics. The upcoming section presents research methodology in more detail.

5 Research Methodology

The following section presents the methodology used to conduct the econometric analysis. The presentation follows Lütkepohl & Krätzig (2004). First, the concept of cointegration is introduced followed by the vector error-correction model (VECM) presentation. The most commonly used model specifications are introduced in the following subsection. Finally, two common tests for cointegration are introduced.

5.1 Cointegration

Cointegration refers to a situation where certain linear combinations of the variables of the vector process are integrated of lower order than the process itself (Juselius 2006, 80). That is, should two or more variables have common stochastic trends, they tend to move together in the long-run. Engle & Granger (1987) define cointegration by stating that the variables of vector $y_t = (y_{1t}, y_{2t}, ..., y_{Kt})'$ are cointegrated of order d, b (denoted $y_t \sim CI(d, b)$) if

1. All variables of y_t are integrated of order d and

2. A vector $\beta = (\beta_1, \beta_2, ..., \beta_K)$ exists such that the linear combination $\beta y_t = \beta_1 y_{1t} + \beta_2 y_{2t} + ... + \beta_K y_{Kt}$ is integrated of order $(d - b)$ where $b > 0$

then β is the cointegrating vector. More generally, variables are cointegrated of order (d, b) if two or more variables are $I(d)$ but at least one linear combination of the variables exists which is of order $(d - b)$ and the coefficient on the $I(d)$ variables are non-zero. Given that y_t has K non-stationary components, there may be as many as $K - 1$ linearly independent cointegrating vectors. The number of cointegrating vectors is called the cointegrating rank of y_t.

Lütkepohl & Krätzig (2004) introduce the basic VAR(p) model of the form

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + ... + A_p y_{t-p} + u_t \tag{5.1}$$

where:
$y_t = (y_{1t}, ..., y_{Kt})'$ set of K time series variables
$u_t = (u_{1t}, ..., u_{Kt})'$ unobservable error term
$A_i = (K\ x\ K)$ coefficient matrices

The error term is assumed to be a zero-mean independent white noise process with time-invariant, positive definite covariance matrix $E(u_t u_t') = \sum_u$. The stability of the VAR process requires that the polynomial defined by the determinant of the autoregressive operator has no roots inside and on the complex unit circle, i.e. that $\det(I_k - A_1 z - ... - A_p z^p) \neq 0$ for $|z| \leq 1$. If however the polynomial has a unit root (i.e. det = 0 for z=1), then some or all of the variables are integrated. If, for convenience, it is assumed that the variables are at most I(1) then it is possible that there are linear combinations of the variables that are I(0), which in turn implies that the variables are cointegrated. For the reason that in (5.1) the cointegration relations do not appear explicitly, Lütkepohl & Krätzig (2004) present a more suitable model for cointegration analysis

$$\Delta y_t = \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + ... + \Gamma_{p-1} \Delta y_{t-p+1} + u_t \tag{5.2}$$

where:
$\Pi = -(I_k - A_1 - ... - A_p)$
$\Gamma_i = -(A_{i+1} + ... + A_p)$ for $i = 1, ..., p-1$.

The VECM form in (5.2) is a result of subtracting the term y_{t-1} from both sides of the VAR(p) model in (5.1) and rearranging terms. The term Δy_t does not contain stochastic trends, because of the assumption that all variables are at most I(1). This implies that the term Πy_{t-1} is the only term in (5.2) that includes I(1) variables. However, given that all the other terms in the equation are I(0), it must be that Πy_{t-1} is I(0) as well, thus it includes the cointegrating relations. The Γ_j parameters ($j = 1, ..., p-1$) are commonly referred to as the short-run parameters of the VECM. Πy_{t-1} in turn is referred to as the log-run relation.

The rank of matrix Π - denoted $rk(\Pi)$ - reveals the number of cointegration relations among the components of y_t. Supposing that $rk(\Pi) = r$, then Π can be written as a product of two (K x r) matrices α and β (and $rk(\alpha) = rk(\beta) = r$), i.e. $\Pi = \alpha\beta'$. Remembering from above that Πy_{t-1} is I(0) implies that βy_{t-1} is I(0) as well. Premultiplying an I(0) vector by some matrix results in an I(0) process. Then because βy_{t-1} can be obtained by multiplying $\Pi y_{t-1} = \alpha\beta' y_{t-1}$ by the matrix $(\alpha'\alpha)^{-1}\alpha'$, the resulting βy_{t-1} remains an I(0) process. βy_{t-1} then contains $rk(\Pi) = r$ cointegrating relations among y_t. The rank of Π is then the cointegrating rank of the system, β is a cointegration matrix and α is known as the loading matrix which contains the weights attached to the cointegrating relations in the individual equations of the model (Lütkepohl & Krätzig 2004, 90).

5.2 Deterministic terms

The basic VECM model in (5.2) usually requires extensions in the form of deterministic terms in order to be able to represent the data generating process. Deterministic terms cover the intercept, linear trends and (seasonal) dummy variables.[11] Consider the process

$$y_t = \mu_t + x_t \tag{5.3}$$

where μ_t is the deterministic part and x_t is the stochastic part which may have a VECM representation as in (5.2). If μ_t is a linear trend term, then $\mu_t = \mu_0 + \mu_1 t$. Multiplying (5.3) by $A(L) = (I_k - A_1 L - ... - A_p L^p)$ where L is the lag operator, noting that $A(L)x_t = u_t$ and again substracting y_{t-1} yields the following equation after manipulation

$$\Delta y_t = v_0 + v_1 t + \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + ... + \Gamma_{p-1} \Delta y_{t-p+1} + u_t \tag{5.4}$$

where:

$v_0 = A(1)\mu_0 + \Big(\sum_{j=1}^{p} j\Gamma_j\Big)\mu_1$

$v_1 = A(1)\mu_1$

Then v_0 and v_1 satisfy restrictions implied by μ_0, μ_1 and coefficients Γ_j. Alternatively (5.4) can be viewed as the basic model without restricting v_0 and v_1. In that case the model can generate quadratic trends if I(1) variables are included. In (5.3) only a linear trends term is allowed.

When testing for the presence of cointegration, the deterministic terms affect the non-standard asymptotic distributions of the Likelihood Ratio (LR) based tests used to determine cointegration rank. Therefore, the various models based on different assumptions on the deterministic term are reviewed below. Again equation (5.3) with $\mu_t = \mu_0 + \mu_1 t$ is considered. In the most restrictive case $\mu_t = 0$ and our model reduces to the basic representation without deterministic terms as

[11] For discussion on further extensions such as exogenous variables in VECM modelling, see (Lütkepohl & Krätzig (2004)

in (5.2). The model could be applied in a situation without linear trends in the levels of y_t and if the variables in y_t had equal means in levels. In a more realistic setting $\mu_1 = 0$ is chosen. Following the reasoning in (5.4) above, we arrive at the VECM form for y_t

$$\begin{aligned}
\Delta y_t &= \Pi(y_{t-1} - \mu_0) + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + u_t \\
&= v_0^* + \Pi(y_{t-1}) + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + u_t \\
&= \Pi^* \begin{bmatrix} y_{t-1} \\ 1 \end{bmatrix} + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + u_t
\end{aligned} \tag{5.5}$$

where $\Pi^* = \begin{bmatrix} \Pi & v_0^* \end{bmatrix}$ and $v_0 * = -\Pi\mu_0$. The intercept is included in the cointegrating vector (long-run relationship). This corresponds to the case where the series have no trends in levels, but the means of the series are unequal. As above, the intercept term can be absorbed into the cointegrating relation or left outside (unrestricted). If however there is a linear deterministic trend in y_t then $\mu_1 \neq 0$. If this trend is absent from the cointegrating relations but included in some individuals variable(s), then $\beta'\mu_1 = 0$ and thus $\Pi(y_{t-1} - \mu_0 - \mu_1(t-1))$ reduces to $\Pi(y_{t-1} - \mu_0)$. The VECM form (5.2) now gives

$$\Delta y_t = v_0 + \Pi y_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + u_t \tag{5.6}$$

where $v_0 = -\Pi\mu_0 + \Big(\sum_{j=1}^{p} j\Gamma_j \Big) \mu_1$

Thus (5.6) assumes that the linear trend is orthogonal to the cointegration relations. Finally, if an unrestricted linear trend term is allowed in equation (5.2) the following VECM form is obtained

$$\Delta y_t = v + \Pi^* \begin{bmatrix} y_{t-1} \\ t-1 \end{bmatrix} + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + u_t \tag{5.7}$$

where $\Pi^* = \alpha \begin{bmatrix} \beta' & -\beta'\mu_1 \end{bmatrix}$ and $v = -\Pi\mu_0 + (I_K - \Gamma_1 - ... - \Gamma_{p-1})\mu_1$

In (5.7) both the variables and the cointegrating relations are allowed to have linear trends. The reason a trend term may be required in the cointegrating relations is that the growth rates of the variables in y_t may differ. Finally, in addition to the considered models, structural changes or breaks in the data generating process have to be considered in model construction. Ignoring breaks in modelling may lead to rejection of cointegration even if the variables are cointegrated. Therefore including dummy variables for structural breaks in the deterministic part of the VAR or VECM process may be justified especially in the case of a break at a known point in time. This implies changes in the asymptotic distributions for Johansen trace test for cointegration rank which have to be accounted for.

5.3 Testing for cointegration

As noted earlier, the rank of the matrix Π in the error correction model (5.2) reveals the number of cointegrating vectors in the process y_t. If $rk(\Pi) = K$, all variables in the system are I(0) and the system is stationary. Similarly, if $rk(\Pi) = 0$ then the term Πy_{t-1} disappears from (5.2) and the equation reduces to an ordinary VAR in differences. In intermediate cases, i.e. when $0 < rk(\Pi) < K$, cointegration is present and a VECM presentation is suitable for cointegration analysis.

A common test for cointegration rank is the Johansen trace test where the test statistic is of the form

$$LR(r_0) = -T \sum_{j=r_0+1}^{K} log(1 - \lambda_j) \tag{5.8}$$

where T are the number of usable observations and λ_j are eigenvalues obtained from the estimated Π matrix. The trace test considers the following sequence of hypothesis until the null hypothesis cannot be rejected:

$$\begin{gathered} H_0 : rk(\Pi) = 0 \quad and \quad H_1 : rk(\Pi) > 0 \\ \vdots \\ H_0 : rk(\Pi) = K - 1 \quad and \quad H_1 : rk(\Pi) = K \end{gathered}$$

Another type of test known as the maximum eigenvalue test use the test statistic

$$LR_{max}(r_0) = -Tlog(1 - \lambda_{r_0+1}) \tag{5.9}$$

which tests $H_0 : rk(\Pi) = r_0$ versus $H_1 : rk(\Pi) = r_0+1$. Both the trace test and the eigenvalue test have non-standard asymptotic distributions which depend on the deterministic terms in the estimated model. The various cases were discussed in the previous section.[12]

[12] In this thesis testing is conducted using both of the introduced test types. For an introduction to another Johansen type test by Saikkonen & Lütkepohl see for example Lütkepohl & Krätzig (2004)

6 Data

This section introduces the data used in the empirical analysis. Sections three and four presented motivation for the choice of house price determinants in empirical modelling. Some additional arguments are presented below. The vector of endogenous variables $y_t = (P_t\ Y_t\ L_t\ IR_t\ MIG_t)$ consists of variables for dwelling prices, household disposable income, household indebtedness, interest rates and total net migration respectively. The data are quarterly observations reaching from 1983/Q1 to 2012/Q4. The base year for all the index series is standardised. The series for house prices, income and loan stock were transformed using natural logarithms. The series were deflated by the cost-of-living index with the exception of the total net migration.

6.1 House prices

The house price indices for the HMA are published by Statistics Finland.[13] The hedonic price indices separate the true price developments as opposed to price developments originating from changes in dwelling characteristics over time. The final index used in this thesis was constructed by linking three different indices of old dwellings prices. The drawback is that the first of the series reaching from 1983 to 2001 considers flats where as the latter two include terraced housing as well. Nevertheless, the constructed index should be a fairly good description of the development of HMA housing prices in the sample period.

[13]Precise data sources concerning Statistics Finland data on house price and disposable income indices, the stock of house loans and total net migration presented in the references under Statistics Finland (b)-(f)

6.2 Income

Household (permanent) income is considered a major determinant of housing consumption in most studies and is also included in this thesis. The quarterly series for household disposable income is constructed by combining two index series published by Statistics Finland. The first is the 'mean disposable monetary income of a household-dwelling unit' for each of the HMA municipalities separately. The corresponding yearly figures for the HMA are computed by applying weights according to the population size of each area and then summing over the four municipalities. Since the regional-level data was unavailable for the entire period of interest, national account data for disposable net income is used to extend the series for the HMA disposable income between 1983 and 1995. The discontinuity is obviously problematic, however presumably the development of inter-regional income inequality between the HMA and the rest of the country was moderate before the IT sector boom of the late 1990's. Furthermore, the data for 2012 is unavailable and the series was lengthened using again national level disposable income data. Finally, the index of wage and salary earnings was used to estimate the quarterly observations from the yearly income data.

6.3 Household indebtedness

Oikarinen (2007) argues that the stock of housing loans is an important source of information concerning fundamentals that affect housing prices. First, increases in perceived permanent income induce households to smooth consumption over lifetime which leads to increased borrowing. Similarly, income uncertainty reflects into borrowing behaviour because of precautionary saving. In addition, current and expected interest rate levels should reflect on household borrowing. Finally, borrowing should reflect changes in the household liquidity constraints as improved availability of credit should relax these constraints. For these reasons it is justified to add a variable describing household indebtedness and the degree of liquidity constraints faced by households.

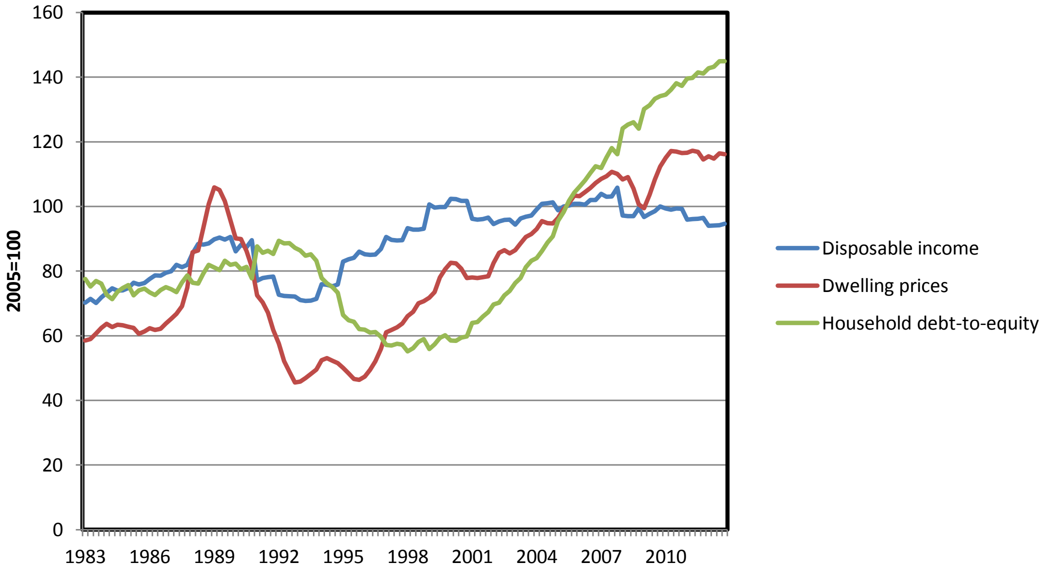

Figure 5: Dwelling prices, disposable income & household debt-to-equity

A variable describing the household debt-to-equity ratio is constructed using data on quarterly stock of household mortgage loans provided by Statistics Finland. The data is only available at national level, thus it has to be assumed that HMA borrowing behaviour resembles national level development.[14] The stock of mortgage loans is in proportion to the household disposable net income in order to scale the proportion of credit in housing transactions.

[14]Support for this assumption is provided in Oikarinen (2007, 106)

6.4 Interest rates

The interest rate series provided by the Bank of Finland describe the average interest rates on mortgages to households and non-profit organisations. The after-tax nominal mortgage rate is computed as $i(1-T)$ where i is the nominal mortgage rate and T is the tax rate. The capital tax rate is used as T from 1993 onwards. Before the year 1993 an average marginal income tax rate was computed to represent T. The average marginal income tax rate was constructed by dividing collected taxes from labour income and social security payments by employee compensation from the annual national accounts by Statistics Finland.

6.5 Demography

Englund (2011, 45) notes that the stock of housing has two main dimensions: the number of dwellings and the quality and size of the average dwelling. An increase in income would primarily affect the demand for quality, whereas a growing population would demand more units. Then, income and demography should have a separate influence on dwelling prices. In this thesis, the total net migration in the Helsinki region is chosen as the 'demographic' variable. Supposedly, migration has caused pressure on house prices in the metropolitan area, especially due to increased immigration to Finland in the recent years. Moreover, total net migration should reflect the 'pull' of the metropolitan area labour markets and the effect of this workforce on HMA dwelling prices especially in the 1990's. Instead of the HMA, the Helsinki region is selected as it is considered an employment area rather than HMA alone. The quarterly total net migration figures were provided by Statistics Finland.[15]

[15] The total net migration series used in the econometric model was seasonally adjusted using Demetra+

The series for real dwelling prices (P_t), household disposable income (Y_t) and the household debt-to-equity (L_t) are presented in figure 5. The average real mortgage rates (IR_t) and the non-adjusted total net migration series (MIG_t) are pictured in figure 6.

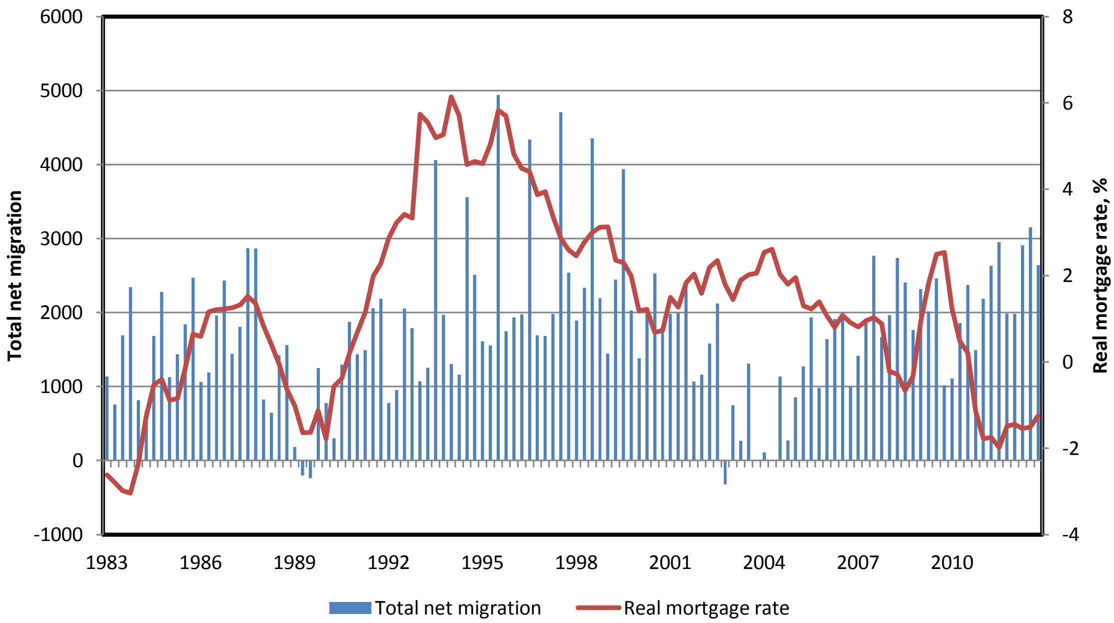

Figure 6: Real mortgage rate & total net migration

All the above variables used in the empirical analysis are demand side variables. As noted in previous sections, the supply side is often hard to account for. Attempts to model house prices with a construction cost index were made, but the variable was eventually left out since it added no information to the cointegrated system. On the contrary, inclusion of construction costs produced nonsensical results for the econometric model. According to test results, the two variable system of real dwelling prices and real construction costs is not cointegrated. The result is not surprising since real construction costs have been fairly stable throughout the sample period.

7 Econometric Analysis

This section presents the results from the cointegration analysis.[16] The analysis is conducted using the methodology introduced in section five on the time series vector described in the previous section

$$y_t = [P_t \;\; Y_t \;\; L_t \;\; IR_t \;\; MIG_t]'$$

The stationarity of the variables in vector y_t was first studied both via visual inspection and the augmented Dickey-Fuller (ADF) unit root test. None of the time series seem stationary (see figures 5 & 6). The original series for total net migration exhibits notable seasonal variation and was seasonally adjusted prior to estimation. Due to the shape of the time series, a constant and a trend were added to the test regressions for P_t, Y_t and L_t. Similarly, the IR_t and MIG_t series were modelled with a constant. Selected unit root test results are summarised in Table 1. Optimal lag length was chosen according to AIC, BIC and Hannan-Quinn criteria. The results of the tests indicate that unit roots cannot be rejected in the levels of any of the variables. With the differenced series, P_t, Y_t and L_t were now estimated with a constant and IR_t and MIG_t without deterministic terms. The differenced series tested stationary with the exception of the L_t series. With variation of the lag length around the initial value of $\rho = 3$, the tests clearly rejected unit root. Thus, modelling could continue by treating all the variables as I(1) variables. Given these integration and trending properties, cointegration between the variables is possible.

[16] JMulTi & gretl software were used for estimation

Table 1: Augmented Dickey-Fuller tests

Variable	Deterministic terms	Lags	Test	CV 1%	CV 5%	CV 10%
P	constant + trend	1	-2.2357	-3.96	-3.41	-3.13
Δ P	constant	0	-4.6504	-3.43	-2.86	-2.57
Y	constant + trend	4	-2.6096	-3.96	-3.41	-3.13
ΔY	constant	3	-3.4349	-3.43	-2.86	-2.57
L	constant + trend	4	-1.4486	-3.96	-3.41	-3.13
ΔL	constant	3	-2.4923	-3.43	-2.86	-2.57
ΔL	constant	2	-4.6106	-3.43	-2.86	-2.57
IR	constant	1	-2.3091	-3.43	-2.86	-2.57
Δ IR	none	0	-8.3301	-2.56	-1.94	-1.62
MIG	constant	1	-2.0359	-3.43	-2.86	-2.57
Δ MIG	none	0	-14.7612	-2.56	-1.94	-1.62

Asymptotic critical values from Davidson & MacKinnon (1993)

A VAR model with a lag length of two, a constant but no trend and with centered seasonal dummy variables was estimated for y_t. Lag length was again chosen by appropriate information criteria. The specification was used to test for cointegration employing both the Johansen trace test and the maximum eigenvalue test. The Likelihood Ratio (LR) based tests for cointegration rank are based on a VAR model where all short-run dynamics, dummy variables and other deterministic components have been concentrated out (Juselius 2006, 131). Further, the distribution of the test statistic is non-standard and based on simulations. Thus, including a deterministic term (unrestricted constant) in the VAR process implies changes in the asymptotic distributions for Johansen trace test for cointegration rank. The critical values and p-values for the trace test are obtained by computing the respective response surface according to Doornkik (1998). The results are summarised in Table 2. Both test statistics indicate a cointegrating rank of one

Table 2: Cointegration test results for VAR(2)

	Trace test		L-max test	
H_0	Test statistic	p-value	Test statistic	p-value
r = 0	89,927	[0,0004]	44,624	[0,0009]
r = 1	45,302	[0,0840]	25,798	[0,0817]
r = 2	19,504	[0,4680]	11,282	[0,6290]
r = 3	8,2226	[0,4492]	7,3811	[0,4539]
r = 4	0,84156	[0,3590]	0,84156	[0,3590]

implying that there is one stationary linear vector between the variables.[17] Next, a VECM(1) based on the VAR(2), that is, with one lag in differences under a rank restriction $r = 1$ was estimated. The estimated cointegrating vector normalised with respect to P_t is shown in Table 3. The estimated β vector can be written as a long-run relation of the form

$$P_t = 0,468\ Y_t + 0,430\ L_t - 0,027\ IR_t + 0,00006\ MIG_t \tag{7.1}$$

The long-run real house price equilibrium equation presents expected results. First, all the coefficients on the cointegrating vector are significant. The coefficients have the expected sign and magnitude, meaning that they are in line with findings from previous studies. According to (7.1), a one per cent increase in real disposable income Y_t increases prices by 0.47 %, holding all else constant. This result is almost identical to Oikarinen (2007). This is no surprise since the data and time period in the study are very similar to this thesis. For example, Kuismanen et al. (1999) and Kosonen (1997) found notably higher long-run income

[17] Detailed results in Appendix A1

elasticity of housing price level of around 0.81 and 1.4, respectively. The elasticity of house prices with respect to household debt-to-equity (L_t) is 0.43 implying that the impact of loosening liquidity constraints is equally important as household income in explaining dwelling prices. Furthermore, house price increases obviously require higher mortgage loans, thus the close connection between the variables comes as no surprise.

Table 3: The cointegrating vector (β) and loading parameters (α) for VECM(1)

	P_t	Y_t	L_t	IR_t	MIG_t
$\hat{\beta}$	1	-0,468	-0,430	0,027	-0,00006
		(-2,4)	(-5,9)	(2,9)	(2,0)
$\hat{\alpha}$	-0,094	-0,054	0,063	-0,477	48,019
	(-5,2)	(-3,0)	(3,4)	(-1,2)	(0,17)

*t-values in parentheses; full model summary in Appendix A2

According to the relation a percentage-point increase in the real mortgage rate reduces prices by 2.7 %. The moderate effect of real mortgage rates - a key component of user cost - is somewhat surprising. On the other hand, more recent evidence on Finnish data (Hofmann (2004), Oikarinen (2007) and Adams & Füss (2010)) find equivalently weak impact for real interest rates. It is possible that the debt-to-equity ratio captures some of the effect. Moreover, Oikarinen (2007, 136) evaluates that especially if the effect of expected future interest rates on house prices is notable, then the anticipated effect of current interest rate is relatively small. Finally, the coefficient on MIG_t implies that an increase of one person in total net migration to the Helsinki region results in a 0.003 % increase in HMA housing prices, ceteris paribus. Equivalently an increase of 1000 in total net migration on a given quarter would raise housing prices by 3 %. Considering the migration flow of the previous decades, it would therefore seem that HMA house prices have been significantly affected by migration. For comparison, a model excluding total net migration was also estimated. The results were very similar to the ones presented with the exception that, expectedly, the coefficient for disposable income now captured some of the effect previously included in the migration variable. This suggests that multicollinearity between these variables might be significant and the estimates of the price relation have to be considered with caution.

The loading parameters α reported in Table 3 provide some support to the long-run model. The result for P_t suggests that dwelling prices adjust 9.4% per quarter towards the long-run relationship following a shock to the system. This equals to annual adjustment of approximately 33%. The estimate of sluggish house prices adjustment is well in line with other housing market studies. Similarly the debt-to-equity ratio (L_t) converges slowly towards long-run equilibrium, at a rate of 6.3% per quarter. This amounts to 23% annually. The remaining loading parameters are either insignificant or of the wrong sign. Finally, an error-correction model for real house price movements presented in Appendix A3 shows that roughly 60% of the variation in quarterly house prices can be explained by the lagged explanatory variables.

Multiple diagnostic tests were conducted on the specification (see Appendix A4). Visual inspection of the individual residual series, autocorrelation and partial autocorrelation functions gives no reason for major concern. The single equation Ljung-Box tests indicate some signs of residual autocorrelation for the disposable income series. The autocorrelation functions do not cross the $\pm 2\sqrt{T}$ approximate 95 % confidence bounds at lower lags for the other series and therefore do not indicate problems. Similarly, residuals from each equation were tested for ARCH effects and only the price equation exhibited some residual heteroskedasticity. However, Juselius (2006) notes that cointegration rank tests are robust against moderate residual ARCH effects. The multivariate Doornik-Hansen test strongly rejects normality in the VECM. Univariate series were checked for normality (not reported) and non-normality was discovered in the income, debt-to-equity and price series. Alternative specifications were estimated, but traces of non-normality remained. However, the non-normality is mainly due to excess kurtosis, which is less serious for estimated results than excess skewness (Juselius 2006, 110). For this reason, and since the α and β estimates proved sufficiently significant, the described specification should be a reasonably good approximation of the long-run relation.

8 Conclusions

Real house prices in the HMA have risen by approximately 99 percent between 1983 and the end of 2012. The rapid increases in house prices especially after the early 1990's depression has regularly brought forward the topic of overheating in the housing market. Even though the speed of real house price appreciation has not been as fast as during the bubble of the late 1980's, it is understandable that the unprecedented price bubble is still remembered in discussion. In Finland, discussion concerning house prices is especially centred around the Helsinki metropolitan area where the highest price rises have often been witnessed. During the recent years, real dwelling prices in the HMA have actually bypassed the peak levels recorded in 1989. The question then remains, whether the price level in the HMA is sustainable in the long-run.

The cointegration analysis of section seven presented a long-run equilibrium real house price level towards which real house prices should adjust. To answer the question on possible overvaluation in the HMA housing markets, figure 7 plots the actual real house prices and the fit from the estimated long-run relation from section seven for the period under consideration. Clearly, the actual prices have far exceeded the long-run price level determined by fundamental factors of house prices applied in this thesis for most of the sample period. At the peak of 1989, the actual price level in the HMA was around 80% above the estimated equilibrium level. Conversely, actual prices were well in line with the fundamentals between 1992 and 1996, the time period which roughly coincides with economic downturn in Finland. Since 1997, actual prices have exceeded the long-run fundamental level by approximately 45% on average. By the end of 2012, real house prices were 32% above the estimated long-run level. Based on these numbers, it seems that real dwelling prices in the HMA have been significantly overvalued for a prolonged period. Actual prices have been significantly above the level suggested by fundamental determinants thus fulfilling the definition of a price bubble.

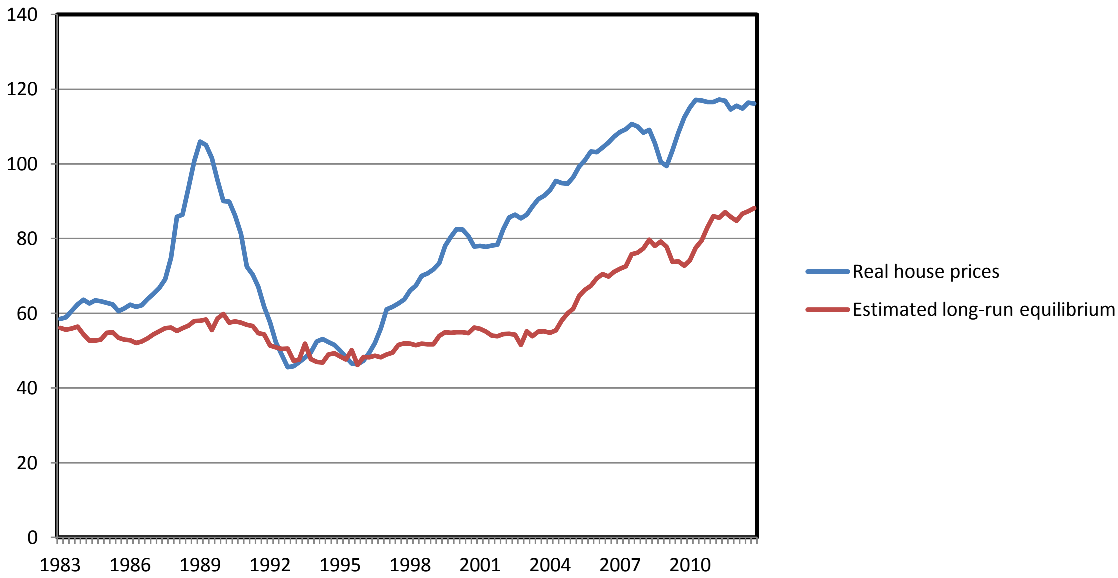

Figure 7: HMA real house prices & the estimated long-run equilibrium prices

It should be emphasized that a high price level on its own does not imply overvaluation. As shown in figure 7, more recently the long-run equilibrium level has risen at approximately the same rate as the actual price level, despite having been nearly constant between 1983 and 2004. This rise of the last decade or so in the long-run level is attributable to notable decreases in real interest rates and equivalently rapid expansion in household indebtedness signalling loosening household liquidity constraints. As shown by the econometric analysis, household real disposable income seems to be an important determinant of house prices, but it has been fairly constant or even declining in the previous years. Therefore it has not been the major 'push' behind real house price rises. On the other hand, increasing total net migration to the HMA has caused notable growth in the long-run price level.

Despite the overvaluation suggested in this thesis, it is far from evident that real prices will fall in the future. As shown by figure 7, real dwelling prices have somewhat stabilised more recently. Then growth in fundamentals can bring the long-run price level closer to actual prices, thus shortening the gap. As shown by the short-run analysis, real house prices also adjust very slowly to the long-run relation. Moreover, at least in nominal terms, house prices have been fairly rigid downwards. It should also be noted that the estimated model is but an attempt at capturing the true price determination process and possibly suffers from data and model misspecification problems. Nevertheless, the increasing population, high level of income and relaxed borrowing constraints combined with scarcity of land and slow supply response in the HMA provide basis for future real housing price increases as well.

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9 Appendix

A1: Cointegration tests

Johansen test:

Number of equations = 5

Lag order = 2

Estimation period: 1983:3 - 2012:4 (T = 118)

Case 3: Unrestricted constant

Log-likelihood = 358,8 (including constant term: 23,9303)

Rank	Eigenvalue	Trace test	p-value	L-max test	p-value
0	0, 31489	89, 927	[0, 0004]	44, 624	[0, 0009]
1	0, 19638	45, 302	[0, 0840]	25, 798	[0, 0817]
2	0, 091179	19, 504	[0, 4680]	11, 282	[0, 6290]
3	0, 060635	8, 2226	[0, 4492]	7, 3811	[0, 4539]
4	0, 0071065	0, 84156	[0, 3590]	0, 84156	[0, 3590]

Corrected for sample size (df = 104)

Rank	Trace test	p-value
0	89, 927	[0, 0007]
1	45, 302	[0, 1013]
2	19, 504	[0, 4845]
3	8, 2226	[0, 4580]
4	0, 84156	[0, 3651]

eigenvalue 0,31489 0,19638 0,091179 0,060635 0,0071065

A2: Summary of estimated VECM system

VECM system, lag order 2

Maximum likelihood estimates, observations 1983:3–2012:4 ($T = 118$)

Cointegration rank = 1

Case 3: Unrestricted constant

Cointegrating vectors (standard errors in parentheses)

PPP_{t-1}	1,00000
	(0,000000)
YYY_{t-1}	−0,468241
	(0,192910)
LLL_{t-1}	−0,430294
	(0,0728385)
IR_{t-1}	0,0272662
	(0,00937487)
$\mathrm{MIGMIGMIG}_{t-1}$	−6,10978e–005
	(3,02370e–005)

Adjustment vectors

PPP_{t-1}	1,00000
YYY_{t-1}	0,575431
LLL_{t-1}	−0,669913
IR_{t-1}	5,09357
$\mathrm{MIGMIGMIG}_{t-1}$	−512,730

Log-likelihood = 1,27916

Determinant of covariance matrix = 6,73306e–007

AIC = $1,1648$

BIC = $2,8084$

HQC = $1,8321$

A3: ECM for P_t

Equation 1: ΔP

	Coefficient	Std. Error	t-ratio	p-value
const	0,0222188	0,00479780	4,6310	0,0000
$\Delta\mathrm{P}_{t-1}$	0,663906	0,0741064	8,9588	0,0000
$\Delta\mathrm{Y}_{t-1}$	0,489090	0,194858	2,5100	0,0136
$\Delta\mathrm{L}_{t-1}$	0,893878	0,187691	4,7625	0,0000
$\Delta\mathrm{IR}_{t-1}$	−0,00844838	0,00427764	−1,9750	0,0508
$\Delta\mathrm{MIG}_{t-1}$	−8,14252e–007	5,79394e–006	−0,1405	0,8885
S1	0,0245732	0,00649477	3,7835	0,0003
S2	0,0168664	0,00726083	2,3229	0,0221
S3	0,0197093	0,00671300	2,9360	0,0041
EC1	−0,0936540	0,0178754	−5,2393	0,0000

Mean dependent var	0,005752	S.D. dependent var	0,037218
Sum squared resid	0,059421	S.E. of regression	0,023456
R^2	0,633355	Adjusted R^2	0,602802
$\hat{\rho}$	−0,044641	Durbin–Watson	2,082316

A4: Diagnostic tests

Equation 1 (P_t): Ljung-Box Q' = 1,17792 with p-value = 0,882

Equation 2 (Y_t): Ljung-Box Q' = 12,4779 with p-value = 0,0141

Equation 3 (L_t): Ljung-Box Q' = 9,36776 with p-value = 0,0525

Equation 4 (IR_t): Ljung-Box Q' = 5,58595 with p-value = 0,232

Equation 5 (MIG_t): Ljung-Box Q' = 1,91022 with p-value = 0,752

Test for ARCH of order 4

Equation 1 (P):

	coefficient	std. error	t-ratio	p-value	
alpha(0)	0,000372682	0,000111820	3,333	0,0012	***
alpha(1)	0,199974	0,0948074	2,109	0,0372	**
alpha(2)	0,188053	0,0966682	1,945	0,0543	*
alpha(3)	0,0238752	0,0966305	0,2471	0,8053	
alpha(4)	-0,139651	0,0948140	-1,473	0,1437	

Null hypothesis: no ARCH effect is present Test statistic: LM = 11,4346 with p-value = 0,0220905

Test for ARCH of order 4

Equation 2 (Y):

	coefficient	std. error	t-ratio	p-value	
alpha(0)	0,000432972	0,000177692	2,437	0,0164	**
alpha(1)	0,0230314	0,0950306	0,2424	0,8090	
alpha(2)	-0,0410366	0,0949563	-0,4322	0,6665	
alpha(3)	0,0488027	0,0949450	0,5140	0,6083	
alpha(4)	0,127884	0,0950550	1,345	0,1813	

Null hypothesis: no ARCH effect is present Test statistic: LM = 2,48032 with p-value = 0,648164

Test for ARCH of order 4

Equation 3 (L):

	coefficient	std. error	t-ratio	p-value	
alpha(0)	0,000400405	0,000155289	2,578	0,0113	**
alpha(1)	0,137279	0,0943628	1,455	0,1486	
alpha(2)	-0,0479978	0,0950149	-0,5052	0,6145	
alpha(3)	-0,0268881	0,0949886	-0,2831	0,7777	
alpha(4)	0,168509	0,0942610	1,788	0,0766	*

Null hypothesis: no ARCH effect is present Test statistic: LM = 5,46792 with p-value = 0,242563

Test for ARCH of order 4

Equation 4 (IR):

	coefficient	std. error	t-ratio	p-value	
alpha(0)	0,203313	0,0602564	3,374	0,0010	***
alpha(1)	0,0579423	0,0947586	0,6115	0,5422	
alpha(2)	0,00162375	0,0947656	0,01713	0,9864	
alpha(3)	-0,0302619	0,0947017	-0,3195	0,7499	
alpha(4)	0,0786509	0,0946463	0,8310	0,4078	

Null hypothesis: no ARCH effect is present Test statistic: LM = 1,15134 with p-value = 0,886043

Test for ARCH of order 4

Equation 5 (MIG):

	coefficient	std. error	t-ratio	p-value	
alpha(0)	120208	34010,9	3,534	0,0006	***
alpha(1)	0,233980	0,0956925	2,445	0,0161	**
alpha(2)	-0,0559097	0,0979680	-0,5707	0,5694	
alpha(3)	-0,0878121	0,0979412	-0,8966	0,3719	
alpha(4)	-0,0226585	0,0956874	-0,2368	0,8133	

Null hypothesis: no ARCH effect is present Test statistic: LM = 7,45238 with p-value = 0,113827

Test for normality of residual

Residual correlation matrix, C (5 x 5)

1,0000	0,083020	0,099304	0,12541	-0,093908
0,083020	1,0000	-0,86979	0,19012	-0,16650
0,099304	-0,86979	1,0000	0,0045213	0,098181
0,12541	0,19012	0,0045213	1,0000	-0,035448
-0,093908	-0,16650	0,098181	-0,035448	1,0000

Eigenvalues of C

0,0942675 0,834918 0,962147 1,17908 1,92959

Doornik-Hansen test

Chi-square(10) = 113,633 [0,0000]

Diagram of fit and residuals for Y

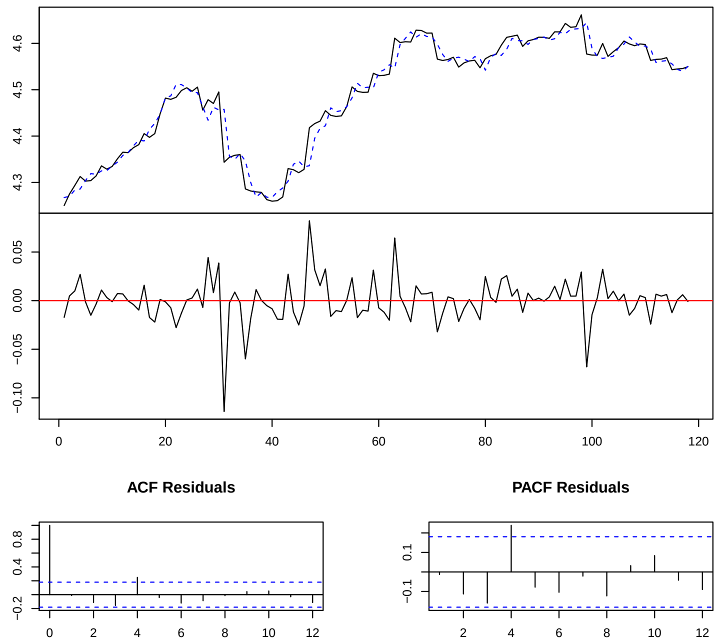
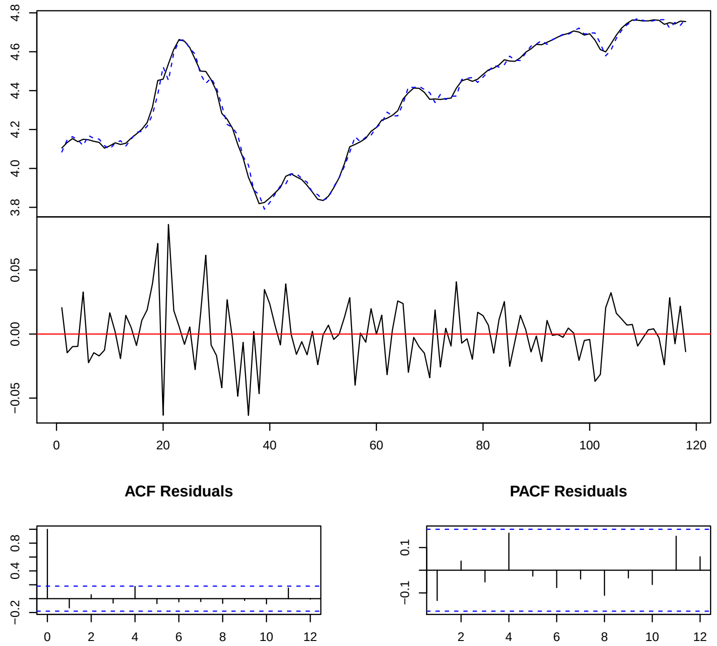


Diagram of fit and residuals for P



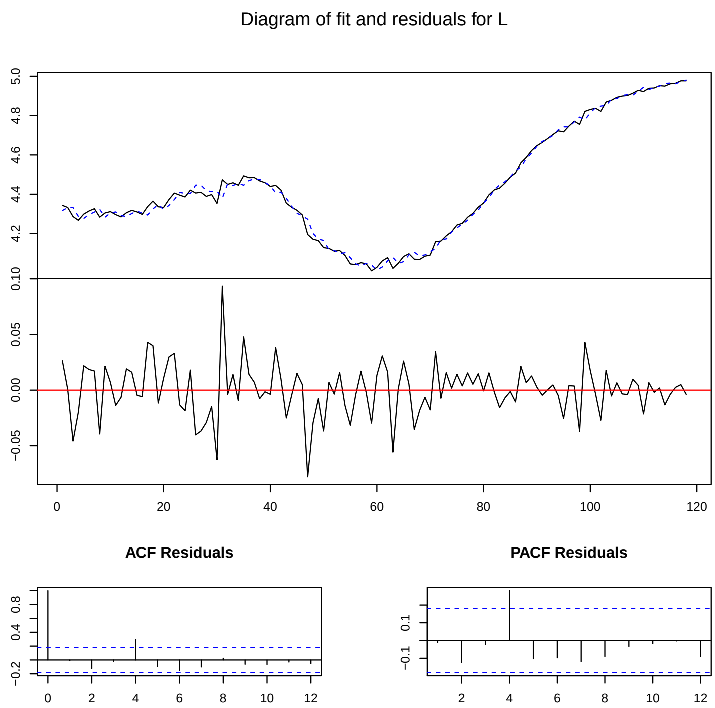


Diagram of fit and residuals for L
5.0
4.8
4.6
4.4
4.2
0.10
0.05
0.00
−0.05
0
20
40
60
80
100
120
ACF Residuals
PACF Residuals
0.8
0.4
−0.2
0
2
4
6
8
10
12
0.1
−0.1

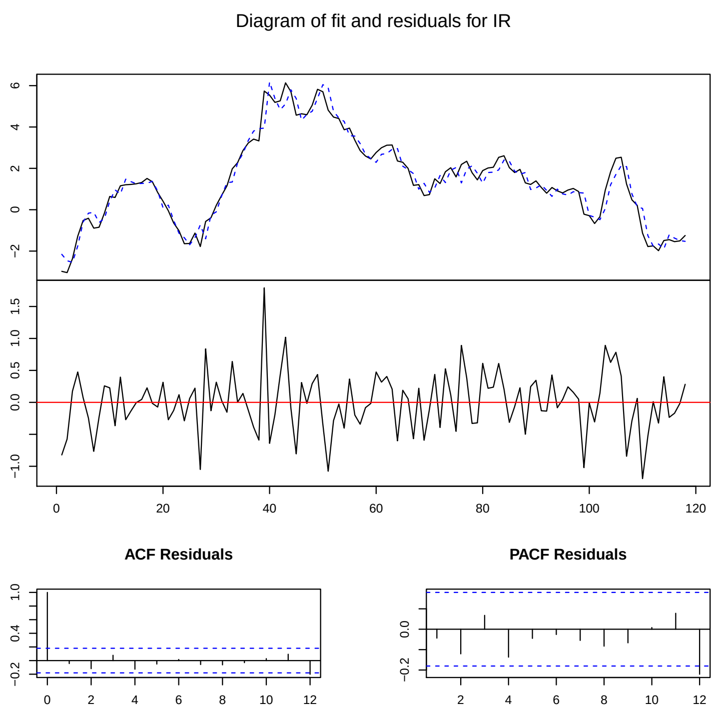


Diagram of fit and residuals for IR
6
4
2
0
−2
1.5
1.0
0.5
0.0
−1.0
0
20
40
60
80
100
120
ACF Residuals
PACF Residuals
1.0
0.4
−0.2
0
2
4
6
8
10
12
0.0
−0.2

Diagram of fit and residuals for MIG